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Biological control of grapevine scales



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Valuable taxonomic support for this project was provided by Mallik Malipatil, Yair Ben-Dov, Emilio Guerrieri, Adam Slipinski, and Marianne Horak. Australian grape growers generously provided information on their cultural practices, and gave access to their vineyards for collection of specimens.

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1. Abstract

The distribution of soft scales that infest grapevines in mainland Australia, their natural enemies, and factors affecting the populations of scales in commercial vineyards were investigated during 2004-2008. Grapevine scale, *Parthenolecanium persicae*, and frosted scale, *Parthenolecanium* near *pruinosum*, were the most common scales, but sometimes occurred in mixed infestations with each other and/or other soft scale species. Soft brown scale (*Coccus hesperidum*), long soft scale (*Coccus longulus*), nigra scale (*Parasaissetia nigra*), and a *Saissetia* sp. were also found on grapevines. Both grapevine scale and frosted scale had one generation per year, reproducing in early spring. *Metaphycus maculipennis* was an effective solitary parasite of juvenile grapevine scale, and gregarious parasite of mature grapevine scale, reducing its reproductive capacity.

2. Executive Summary

A study of soft scales affecting grapevines has determined the scales and beneficial insects that are present in Australia's grape regions, and identified factors influencing the distribution, abundance, and economic importance of soft scales in commercial vineyards. The study was carried out by a PhD student, Mr. Adrian Rakimov, supported by an Australian Research Council Linkage Grant, and funded by the Grape and Wine Research and Development Corporation, Victorian Department of Primary Industries, and the University of Melbourne.

Surveys of the main grape regions of mainland Australia showed that grapevine scale, *Parthenolecanium persicae*, and frosted scale, *Parthenolecanium* near *pruinosum*, were the most common scales, but sometimes occurred in mixed infestations with each other and/or other soft scale species. Soft brown scale (*Coccus hesperidum*), long soft scale (*Coccus longulus*), nigra scale (*Parasaissetia nigra*), and a *Saissetia* sp. were also found on grapevines. An expert taxonomist, Dr. Yair Ben-Dov, has advised that the identity of frosted scale in Australia requires further investigation, as specimens are not identical to the type descriptions of frosted scale. The status of "frosted scale" in Australia needs to be resolved through further taxonomic and molecular research, in collaboration with expert taxonomists, to clarify whether "*Parthenolecanium* near *pruinosum*" is a distinct species of scale. This in turn will have implications for any future research on the potential to introduce parasitoids to Australia for biological control of frosted scale.

Grapegrowers may overlook or underestimate the presence of soft scales in vineyards, due to the small size and cryptic habits of the scales. Identification of the juvenile stages of different scale species is difficult. The scales are most obvious after leaf fall in winter, but their numbers are often underestimated because many scales are on the underside of canes or spurs, and underneath bark on the trunk or cordon of the vines. Surveys of vineyards for grapevine scales need to be extensive, as the scales are usually distributed across most of the vineyard. While surveys are more effective and easier in winter, the presence of ants on grapevines is a good indicator of the presence of soft scales or other honeydew producing insects during the growing season.

Populations of soft scales (predominantly grapevine scale, but also frosted scale and soft brown scale) in a commercial Chardonnay vineyard were influenced by cultural practices, and the activity of natural enemies. Mechanical pruning in winter removed both wood and scales on the wood. Both grapevine and frosted scales had predominantly female populations, similar life cycles, and generally only one generation per year.

In autumn and early winter, juvenile scales moved from leaves to the shoots and wood of the grapevines. In late winter and spring, they grew to mature females and produced up to 5000 eggs. At this stage, grapevine and frosted scale could be distinguished by the shape and colour of the adult female and the colour of the eggs. The adult females died after laying eggs, which

remained under the body of the dead female until the crawlers hatched. The crawlers colonised the leaves and shoots of grapevines after budburst, settling on the emerged leaves and shoots.

In spring and summer, the young scales were mostly on the underside of the basal leaves of the shoots, but difficult to see without a microscope or magnifying hand lens due their small size and translucent appearance. One obvious clue to the presence of soft scales on grapevines was the activity of ants, which attended the juvenile and maturing scale to harvest honeydew excreted by the scales. The scales remained on the leaves and green shoots, growing slowly during the summer months, until moving from the leaves and shoots in autumn.

A feature of the scale populations was the big reduction in numbers of juvenile scales on leaves during summer. The cause(s) of this reduction was not determined, but it may be associated with high temperatures and parasitism or host feeding by parasitoids, particularly *Metaphycus maculipennis*.

In this study, *Metaphycus maculipennis* was the most abundant and effective parasitoid of grapevine scale, *Parthenolecanium persicae*. Although the maximum rate of parasitism was only about 20% in October 2006, previous observations have indicated parasitism rates of over 60% of mature female grapevine scales in some years (Buchanan, unpublished). The causes of the apparent differences between seasons in rates of parasitism, confirmation of the parasitoid effects on reproductive potential of grapevine scale, and the parasitoid life cycle during summer and autumn are issues that remain to be resolved.

Molecular diagnostic techniques were explored in this study for their potential applications as quick and reliable diagnostic tools for both adult and juvenile stages of the scales. The amplification of hymenopterous DNA from the scales shows the further potential to determine which parasitoids are parasitising which scales, and when. Further research into the practical application of molecular technologies in insect ecology should be an area of strategic investment by research agencies seeking to provide the knowledge required to achieve sustainable integrated pest management.

Once the taxonomy of frosted scale is determined, industry funders (GWRDC and HAL) should consider a feasibility study into increasing the biological control of soft scales on grapevines and fruit trees in Australia. The applied research on biological control of citrus scale pests by the late Dan Smith of QDPI, in conjunction with suppliers of biological control agents and IPM services, is an inspirational model for future work.

Descriptions and photographs of soft scales are presented as an extension publication will help grapegrowers to recognise and manage scale populations in their vineyards. The extension publication should be used in a series of practical workshops for grapegrowers, preferably carried out in late winter in regional areas, and led by viticultural extension specialists. The objectives of the workshops would be to provide grapegrowers with the information required to identify their soft scale pests, and to decide on the best options for sustainable control.

3. Background

Grapevine scale and frosted scale are common pests of grapevines in Australia, which sometimes develop into damaging infestations that warrant insecticidal control, either with a dormant oil spray, or an early spring insecticide application. The effect of the insects is to weaken canes, and foster ant populations in the vineyard through their excretion of honeydew. The control treatments also disrupt biological control agents for other vine pests, by reducing populations of predatory mites, lacewings and ladybirds early in the season.

There has been no published study on the ecology or biological control of these scales on their various hosts in Australia. However, biological control is thought to be important in regulating the scale populations, and it is recorded that grapevine scale is attacked by *Metaphycus spp.*, which are well known and effective parasitoids of soft scales. However, frosted scale is not known to have effective parasitoids in Australia, although in California *Metaphycus californicus* is reported as regulating the pest (Anon.1987).

This report is based on a 3 year PhD project, carried out by Mr. Adrian Rakimov, which aimed to identify soft scales and investigate their distribution, abundance, and biological control in Australian vineyards. The expected long term outcome will include identification of opportunities to improve biological control of the scales by introductions of parasitoids from different regions or crop hosts within Australia. A short term outcome will be additional knowledge that will improve IPM strategies for control of grapevine and frosted scale.

The report discusses the distribution of the different soft scales that infest grapevines in Australian vineyards, the natural enemies associated with these scales, and factors affecting the distribution and abundance of the scales in a commercial vineyard.

4. Project aims and performance targets

The specific aims of this project were to:

1. To define a research program on biological control of grapevine scales which will deliver practical benefits to grape growers, and the opportunity for postgraduate training (PhD).
2. To determine the distribution and identity of different grapevine scales, and their main parasitoids, in the various grape growing regions of Australia.
3. To conduct a literature review of biological control of soft scales, including taxonomy of their parasitoids.
4. To survey the distribution and impact of biological control of grapevine scales in Australian vineyards.
5. To recommend, and where appropriate act on, opportunities to improve biological control of grapevine scales.
6. To produce a PhD thesis, and practical IPM guides, from the project work.

Outputs and Performance Targets 2004-05

Outputs	Performance Targets
1. ARC Linkage grant approved, and student appointed to the project.	Successful application for PhD support, and high quality student appointed by January 2005.
2. To define a research program on biological control of grapevine scales which will deliver practical benefits to grape growers, and the opportunity for postgraduate training (PhD).	Documented research plan, endorsed by supervisors as suitable PhD standard. Draft plan documented by June 2005.
3. Literature review of grapevine scales and their biological control agents.	Literature review documented, and endorsed by supervisors as suitable for PhD standard. Draft of literature review available by June 2005.

Outputs and Performance Targets 2005-06

Outputs	Performance Targets
1. A survey of grower attitudes to and control practices for grapevine scales	Publishable report suitable for extension journal by June 06.
2. Establishment of glasshouse cultures of scales and host plants.	Viable cultures of grapevine scales, and frosted scale, established under controlled environments by March 06.
3. Progress report on experiments and activities for 05/06	Report, including statistical analysis and interpretation, to standard of draft paper by June 06.

Outputs and Performance Targets 2006-07

Outputs	Performance Targets
1. Field sites for IPM studies on scales established.	Experimental sites and treatments selected by July 2006.
2. Progress report on experiments for 06/07	Report, including statistical analysis and interpretation of field and laboratory experiments, to standard of draft paper by June 07.

Outputs and Performance Targets 2007-08

Outputs	Performance Targets
1. Final technical report on project prepared	Report to standard of draft thesis by December 2007 (deferred to August, 2008).
2. An illustrated fact sheet defining the key findings of the project for industry audiences.	High quality, colour plates, and endorsed by the DPI publication process as suitable for publication by March 2008 (deferred to June, 2008).
3. A report on the distribution of beneficial fauna, and impact of biological control of grapevine scales.	The report, prepared by March 2008, would be endorsed by the supervisors as suitable content for the PhD thesis (deferred to June, 2008).

5. Methods

The six aims of the project were achieved through two main technical objectives; firstly to determine which scales and beneficial insects were present in Australia's grape regions, and secondly, to identify the main factors that affect the distribution, abundance, and economic importance of grapevine scales in commercial vineyards. Consequently, this report will focus on the technical objectives in describing the methods and discussing the results, outcomes and conclusions.

5.1 Identity and distribution of soft scales in the grape growing regions of mainland Australia

To determine the species, distribution and aspects of biology and ecology of soft scales on grapevines, scales were collected from grapevines and other hosts between 2005 and 2008. Scales were collected from a total of 65 sites, of which 51 were commercial winegrape vineyards, with the remainder being table grape vineyards or other host trees in orchards, residential, and public sites. A small number of scale specimens were also collected by others and sent to DPI Victoria for examination.

The collections were made from Swan District (WA), Perth Hills (WA), Pemberton (WA), Margaret River (WA), Riverland (SA), Padthaway (SA), Barossa Valley (SA), Coonawarra (SA), Murray Valley (VIC/NSW), Rutherglen (VIC), Yarra Valley (VIC), Riverina (NSW), Mudgee (NSW), Hunter Valley (NSW) and the Granite Belt (QLD). Some of these winegrape growing regions were visited several times.

Scales and associated insects were bought back to DPI Mildura in ethanol or on plant material, in accordance with interstate quarantine requirements, and examined under a dissecting microscope. Representative specimens were slide mounted, and identified using taxonomic keys. Provisional identifications were confirmed by specialist taxonomists.

Identification of soft scales based on genetic differences is potentially an accurate and rapid method of diagnosis, which can be applied to all life stages of the scales. The project aimed to develop a protocol for the extraction of Coccid DNA, and produce sequence data for the *cytochrome oxidase* subunit 1 region of the mitochondrial DNA, which could then be applied to identification of coccid species found in Australian vineyards. The mitochondrial DNA (CO1) sequences were used to separate the species of soft scales on grapevines, and to support the identifications based on morphological characters.

Anecdotal information refers to grapevine scales as being found along the edges of vineyards, particularly alongside roads or tracks within the vineyard. The distribution of scale-infested grapevines was sampled in 14 vineyard blocks, to determine if within vineyard distribution was random or aggregated. This was achieved by inspecting individual vines according to a sampling plan that aimed for an even spatial distribution across the vineyard block. Results were mapped and the distribution of the scale infested vines were analysed.

5.2 Natural enemies and other species associated with soft scales

Work on biological control of scale insects commenced in 1901, when the Government of Western Australia appointed a Californian entomologist, George Compere, to introduce biological control agents against exotic insect pests (Wilson 1960). Compere introduced several predators and parasitoids of Coccids to Western Australia during 1902 – 1910. Some of these were subsequently introduced to and released in the horticultural regions of the eastern States. These introductions were targeted at a range of scale species affecting fruit trees and grapevines, including grapevine scale, *Parthenolecanium persicae*, black scale, *Saissetia oleae* and soft brown scale, *Coccus hesperidum.*

The introductions included several ladybird beetles that are now considered useful predators, such as *Cryptolaemus montrouzieri*. Some of the parasitoids introduced by Compere were unidentified, and there is confusion about the correct identity of some of the introduced parasitoids. Consequently, the current study has collected predators and parasitoids from soft scale in many vineyards of mainland Australia. In view of the effects of ants on biological control, the ant species associated with soft scales on vineyards were also collected and identified.

5.3 Distribution and abundance of soft scales in a commercial vineyard

The abundance and within vine distribution of soft scales (predominantly grapevine scale, but also frosted scale and soft brown scale) were studied during 2006 and 2007 in a commercial wine grape vineyard at Merbein, Victoria. A single cane was removed from each of 5 randomly selected grapevines at intervals of 4-6 weeks between March 2006 and December 2008. The canes were examined under a microscope in the laboratory, and the number of grapevine scales counted on the leaves and internodes of each cane.

The predators and parasitoids associated with the soft scales were also recorded at each sample date on both the randomly selected canes, and by rearing insects from a separate sample of scales collected from other parts of the vineyard at each sample date.

6. Results and discussion

6.1 Identity and distribution of soft scales in the grape growing regions of mainland Australia.

There are six species of soft scales (Family Coccidae) recorded on grapevines in Australia, all of which are cosmopolitan and have a wide range of host plants. Grapevine scale, *Parthenolecanium persicae,* is recognised as the main scale pest of grapevines in Australia, but is also recorded in from pome and stone fruit trees. Other soft scales are recorded on grapevines in Australia, but are better known as pests of fruit trees. Frosted scale, *Parthenolecanium pruinosum*, is recorded as a pest of stone fruit trees, while black scale, *Saissetia oleae* and soft brown scale, *Coccus hesperidum*, are well known pests of citrus. Nigra scale, *Parasaissetia nigra*, and long soft scale, *Coccus longulus*, are occasional pests of subtropical fruit trees and ornamentals.

The surveys carried out in this project have shown that grapevine scale is the most commonly encountered species of soft scale, being present at approximately 59% of sites with scale infested grapevines. However, frosted scale, and soft brown scale were more common than may have been expected from the literature, being collected from approximately 52% and 13% of sites with grapevines, respectively.

The identity of “frosted scale” in Australia has been questioned by Dr. Yair Ben-Dov, an expert in taxonomy of scale insects. Dr. Ben-Dov has advised that the specimens of “frosted scale” from Australia are different to type specimens identified as *Parthenolecanium pruinosum*, and the Australian specimens should be referred to as *Parthenolecanium* near *pruinosum*. Further taxonomic and molecular studies are required to clarify the taxonomic status of “frosted scale” from Australia. Until the taxonomy of “frosted scale” from Australia has been determined, it is not known whether or not there is one or more species (i.e., *P. pruinosum* and *P.* near *pruinosum*) present in Australian vineyards and on other host plants. For the purpose of this report, the term “frosted scale” is used as a common name for both *Parthenolecanium* near *pruinosum* and *Parthenolecanium pruinosum* in this study.

Grapevine scale and soft brown scale were found on grapevines in all mainland States. Frosted scale was collected from Victoria, South Australia, and New South Wales, but not in Western Australia and Queensland, although it is known to occur on other host plants there. Long soft scale was collected from table grapes in Perth and Carnarvon, winegrapes in Margaret River, and winegrapes in the Hunter Valley.

More than one species of soft scale occurred in the same vineyard, and sometimes on the same vine (Table 1), which complicates the identification of the scale species, particularly when scales are immature. Mixtures of grapevine scale and frosted scale were found at 10 of the sites sampled. Five other sites had mixtures of 2 different scale species, two sites had three scale species, and one site had 4 scale species.

Table 1. The occurrence of scale species on grapevines in mainland Australia (data from Rakimov 2008, in preparation)

Soft scale species present on grapevines	Number of sites	Location of sites (State and region)
Grapevine scale *(Parthenolecanium persicae)* only	2 2 4 3 5	WA – Swan Valley SA – Riverland, Vic – Swan Hill, Rutherglen, Sunraysia, Yarra valley NSW – Hunter Valley, Riverina, Sunraysia Qld – Granite Belt
Frosted scale (*Parthenolecanium* near *pruinosum)* only	7 3 5	SA – Adelaide Hills, Coonawarra, Padthaway,Riverland Vic – Rutherglen, Yarra Valley NSW – Mudgee, Riverina, Sunraysia
Nigra scale (*Parasaissetia nigra)* only	1 1	WA – Swan Valley Vic – Sunraysia
Soft brown scale (*Coccus hesperidum*) only	1	Vic – Sunraysia
Long soft scale *(Coccus longulus)* only	1	WA – Perth
Saissetia *sp. only	1	Vic – Sunraysia
Grapevine scale and frosted scale	3 5 2	SA – Barossa Valley, Padthaway Vic – Swan Hill, Rutherglen, Sunraysia, Yarra Valley NSW – Mudgee, Riverina
Grapevine scale and soft brown scale	1 1	WA – Gin Gin Vic – Sunraysia
Grapevine scale and long soft scale	1 1	WA – Margaret River NSW – Hunter Valley
Grapevine scale, frosted scale, and soft brown scale	3	Vic – Sunraysia
Grapevine scale, frosted scale, soft brown scale, and nigra scale	1	SA – Riverland
Grapevine scale, nigra scale, and *Saissetia** sp.	1	WA – Pemberton
Long soft scale and *Saissetia** sp.	1	WA – Carnarvon

* The *Saissetia* sp. was probably black scale, *Saissetia oleae*, but this was not confirmed by taxonomic examination.

Detection of grapevine scales in vineyards

Grapevine scale, *P. persicae*, reproduces after budburst in spring (September to October), and the crawlers settle predominantly on the lower leaf surfaces of basal leaves, where they are extremely difficult to detect without a thorough search and the aid of a hand lens. During the growing season, the scales are mostly on the underside of leaves, but as leaves senesce they move onto the lignified wood of the vine, where they are more obvious after leaf fall. Overwintering juvenile scales were also observed on trellis wires.

Grape growers are most likely to observe dead adult scales from the previous season, and also live juvenile scales during vine dormancy, particularly during pruning.

The presence of ants on the trunk and canopy of grapevines is a good indicator of the presence of honeydew producing insects, including soft scales and mealybugs, on the vines. In some cases the spots of honeydew can be seen on leaves or irrigation lines. Grapevines with severe infestations of honeydew producing insects may have a blackened appearance, due to the growth of sooty moulds on the honeydew, although black moulds also grow on other sugar sources including unpicked bunches or berries.

It can be difficult to distinguish the different soft scales found on grapevines, particularly juvenile stages. However, mature females of the different species do have characteristic features (Table 2).

Table 2. Characters that can help to visually distinguish different soft scales found on grapevines in Australia.

Scale species	Mature females	Eggs and/or crawlers
Grapevine scale	Oval shape, about 7mm long, dark brown scale.	Yellow eggs laid in mass beneath the body of the adult scale, crawlers yellow.
Frosted scale	Oval shape, 6-8mm long, strongly convex. Scale dark brown, sculptured and covered with white powdery wax.	White eggs, laid in mass beneath the scale body. Crawlers white.
Soft brown scale	Oval shape, 3-4 mm long, yellow-brown mottled with brown spots.	Crawlers are light brown, born alive.
Black scale	Oval shape, 3-5 mm long, convex, scale black to dark brown. Ridges on top surface of scale forming a "H" shape, most obvious in early stage adults.	Pink eggs, laid in mass beneath the scale. Crawlers light brown.
Nigra scale	Oval shape, 3-4 mm long. Smooth, shiny dark brown to black scale.	Eggs laid in mass beneath the scale, crawlers light brown.
Long soft scale	Elongate oval shape, 4-6 mm long, yellow to grayish brown, with visible eye spots.	Crawlers born alive.

Molecular techniques for identification of soft scales on grapevine

The soft scale species found on grapevines in Australia showed high interspecific and low intraspecific sequence variation in the studied region of the CO1 gene, making the gene suitable for use in species discrimination. Polymerase chain reaction (PCR) products from soft scales were always single banded with 385 nucleotides (minus the primers), regardless of the scale species or instar.

Analysis of the sequences showed six distinct clades, each representing a single species. The variation in intraspecific sequences was low. Grapevine scale (n = 28), and long soft scale (n = 2) had identical intraspecific sequences.

In contrast, frosted scale (*P.* near *pruinosum*) and nigra scale both showed intraspecific sequence divergence of 0.26%, representing a difference in one base pair. It is interesting to note that, although small, the sequence divergence for nigra scale separates Western Australian and Victorian individuals which may reflect a separate origin or independent divergence since introduction.

The low levels of variation for intraspecific sequence divergence may reflect the predominantly parthenogenetic reproduction of soft scales. Sequences of grapevine scale collected from sites where conspecific males were found were identical to individuals from populations without

males. Also, frosted scale (*P*. near *pruinosum*) collected from three different host plants shared identical sequences. However this will need to be verified with the characterization of nuclear marker variation.

Individuals from the putative second annual generation of *P. persicae* (for details see Rakimov 2008, in preparation) had identical sequence to all other *P. persicae* analysed in this study. This finding corresponds with morphological identifications of other individuals of what may be a second generation of *P. persicae*. Thus, in Australia, that *P. persicae* appears to be at least partly multivoltine in some instances.

The molecular diagnostic techniques developed in this study have the potential (subject to further taxonomic and molecular studies on *P*. near *pruinosum*) to allow rapid and accurate identification of soft scales, including juveniles, at any time of the year.

Scales collected for analysis were not visibly parasitised, but several thel sequences analysed were hymenopterous in origin. This suggests amplification of parasitoid DNA (probably from eggs or very young larvae) from soft scales in the parasitised individuals during the polymerase chain reaction. It also signals the possibility of unrecognised parasitism where parasitoid eggs are quiescent in the host scale.

Spatial distribution of scales in vineyards

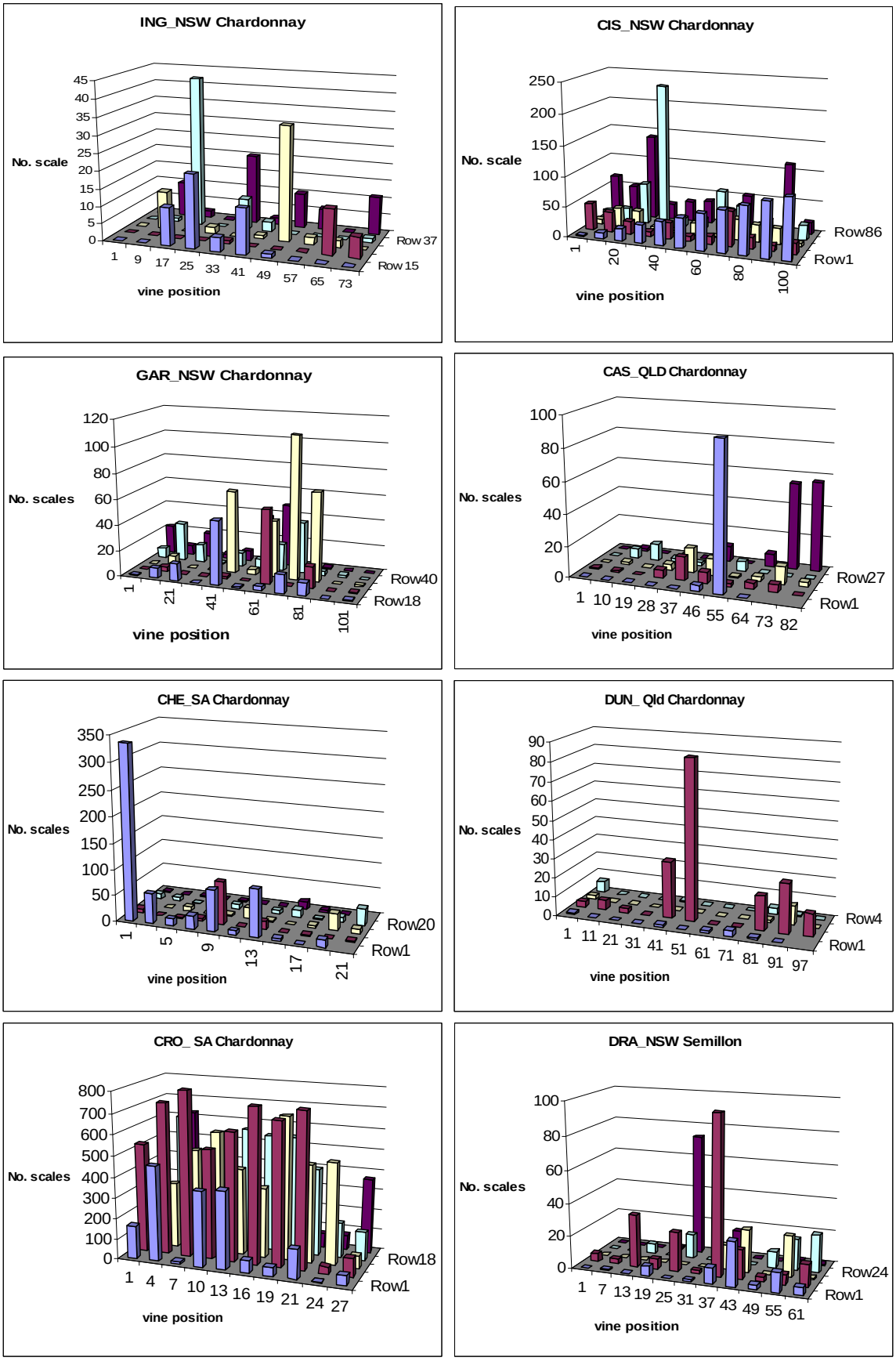
The vineyards surveyed for vine scales were nominated by their managers to be infested by scale insects, consequently they are a biased sample with respect to scale infestation. The numbers of scales on different vines were highly variable (Table 3). Of the 722 vines inspected across the 14 vineyards, 211 (29%) were apparently free of scales, and 44% were infested by 1-20 scales (Table 3).

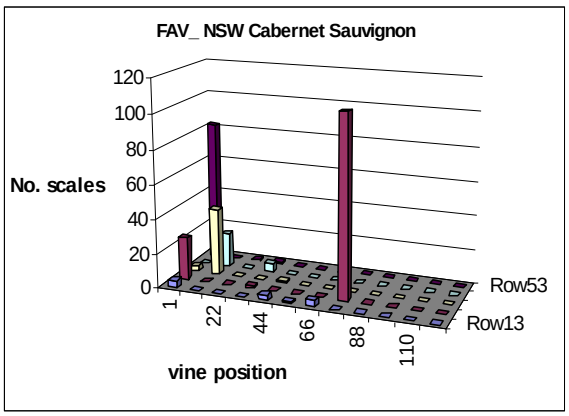
Table 3. Scale density in vineyards surveyed for grapevine scales. (Data summarised from Rakimov 2008, in preparation)

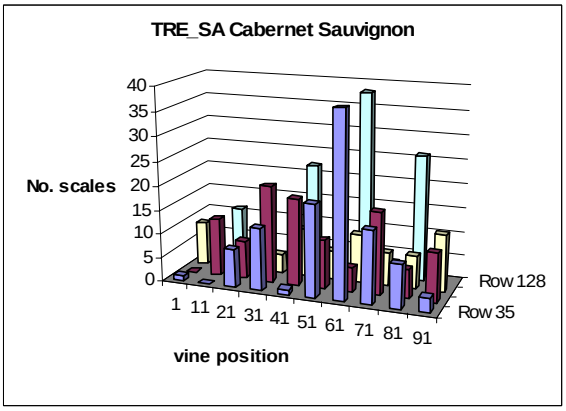
Summary of vineyard surveys			
Vineyard ID_State Variety	**Scale species present**	**Mean number of scales per vine**	**Range (scales per vine)**
ING_NSW Chardonnay	Soft brown scale	5	0-43
CIS_NSW Chardonnay	Frosted scale	43	0-228
GAR_NSW Chardonnay	Grapevine scale	14	0-110
CAS_Qld Chardonnay	Grapevine scale	7	0-92
DUN_Qld Chardonnay	Grapevine scale	5	0-84
CHE_SA Chardonnay	Grapevine scale, frosted scale, soft brown scale, nigra scale	18	0-335
CRO_SA Chardonnay	Grapevine scale	>390	2->800
DRA_NSW Semillon	Grapevine scale	9	0-96
FAV_NSW Cabernet Sauvignon	Grapevine scale	5	0-106
TRE_SA Cabernet Sauvignon	Frosted scale	7	0-38
CIS_NSW Riesling	Frosted scale	39	3-140
CAR_NSW Columbard	Grapevine scale	17	1-168
LUD_SA Ruby Cabernet	Grapevine scale	7	0-98
KOM_Qld Shiraz	Grapevine scale	116	0-628

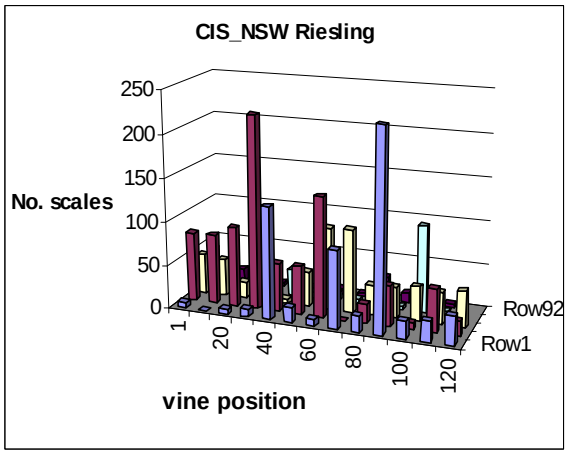
The distribution of scale infested vines in most vineyards was random, but aggregated in a few vineyards with high scale numbers (Figure 1). There were no obvious edge effects. This suggests that surveys of vineyards for scales need to be extensive, to increase the chances of finding scales and groups of vines with high densities of scale.

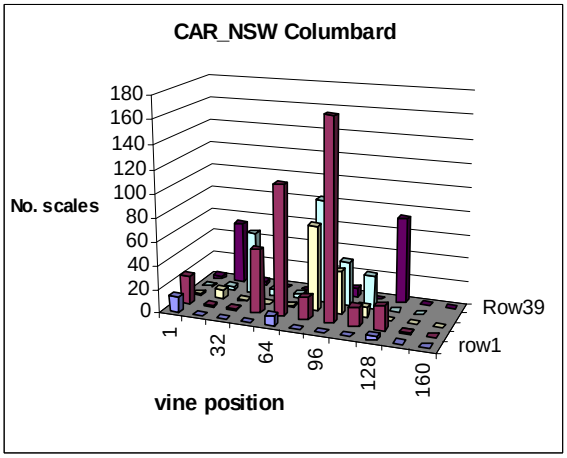
Figure 1. Spatial distribution of grapevine scales recorded on individual grapevines in surveys of 14 different vineyards in eastern Australia.

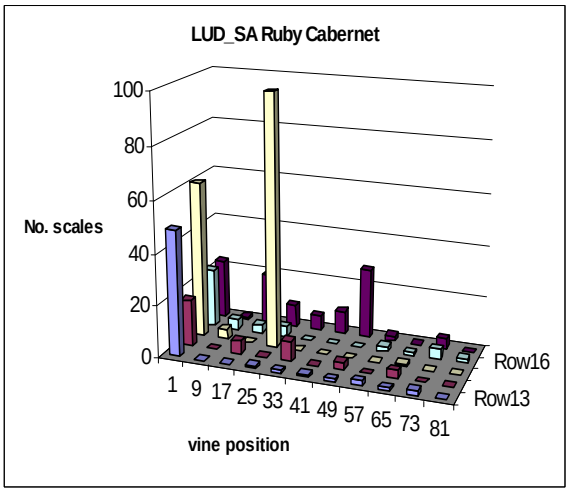


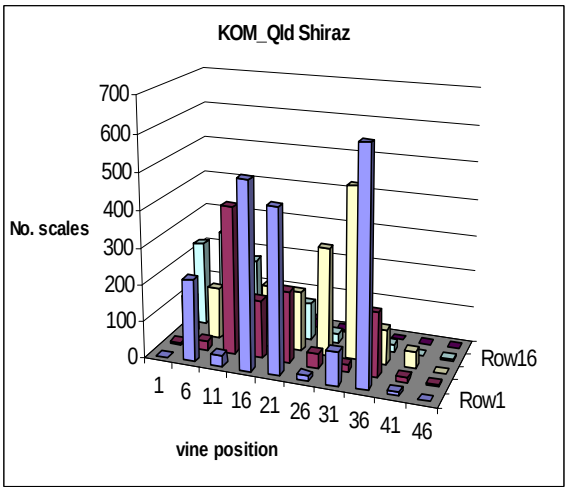

FAV_ NSW Cabernet Sauvignon
No. scales
120
100
80
60
40
20
0
1
22
44
66
88
110
vine position
Row53
Row13


TRE_SA Cabernet Sauvignon
No. scales
40
35
30
25
20
15
10
5
0
1 11 21 31 41 51 61 71 81 91
vine position
Row 128
Row 35


CIS_NSW Riesling
No. scales
250
200
150
100
50
0
1
20
40
60
80
100
120
vine position
Row92
Row1


CAR_NSW Columbard
No. scales
180
160
140
120
100
80
60
40
20
0
1
32
64
96
128
160
vine position
Row39
row1


LUD_SA Ruby Cabernet
No. scales
100
80
60
40
20
0
1 9 17 25 33 41 49 57 65 73 81
vine position
Row16
Row13


KOM_Qld Shiraz
No. scales
700
600
500
400
300
200
100
0
1 6 11 16 21 26 31 36 41 46
vine position
Row16
Row1

6.2 Natural enemies and other species associated with soft scales

Parasitoids

Over 5000 parasitoids were collected from soft scales in grapevines, and on fruit trees near vineyards, in the mainland states of Australia. The parasitoid specimens were initially identified on the basis of morphological similarity (morphospecies), and a sample of each morphospecies was then identified to genus, and if possible to species.

The most common parasitoid collected was *Metaphycus maculipennis*, representing 79.6% of all specimens. Other common parasitoids were *Cheiloneurus* spp. (9.6%), and *Coccophagus spp.(6.7%).* Other parasitoids occurring in small numbers or only a few vineyards were *Coccophagus ceroplastae* (1.6%), *Euryischomyia flavithorax* (0.8%), *Metaphycus* sp. (0.9%), *Ophelosia bifasciata* (0.7%),*Metaphycus helvolus* (0.4%), *Myiocnema comperei*, *Moranila californica*, *Scutellista caerulea*, and *Microterys nietneri*.

Metaphycus maculipennis was only collected from vineyards where *Parthenolecanium persicae* was present as the sole host or in combination with *Coccus hesperidum* or *Parthenolecanium* near *pruinosum (*Table 4). While *M. maculipennis* has also been recorded from *Parthenolecanium corni*, no *P. corni* were found in vineyards sampled in the present study.

The large number of *M. maculipennis* collected is due to the predominance of *P. persicae* in Australian vineyards, and because it a gregarious parasitoid of the mature female scales. *Cheiloneurus* spp. were closely associated in this study with *M. maculipennis*, often emerging from the same grapevine scale as *M. maculipennis. Cheiloneurus* spp. were abundant in the same vineyards (Table 4), and at the same collection dates as *M. maculipennis* (Fig. 2). The *Cheiloneurus* specimens, which consisted of two morphospecies, are hyperparasitoids of *M. maculipennis*.

Metaphycus helvolus was collected from vineyards where grapevine scale, soft brown scale, and long soft scale were present. *M. helvolus* is a solitary and gregarious endoparasitoid of soft brown scale, nigra scale, and several other soft scales.

*Coccophagus spp. (*representative specimens identified as *Coccophagus lycmnia* and *C. semicircularis*) were abundant in the vineyards where grapevine scale, frosted scale, and soft brown scale were present. They parasitise juvenile scales of several species of soft scales. *Coccophagus ceroplastae* was only found in vineyards where long soft scale was present, and is a common parasitoid of this scale (Waterhouse and Sands, 2001).

Euryischomia flavithorax is an Australian native, and was collected from vineyards with soft brown scale and grapevine scale. It is not certain whether this is a parasite or hyperparasite of soft scales. *Ophelosia bifasciata* is also considered indigenous, and in this study was found in vineyards with grapevine scale, or where soft brown scale and frosted scale were also present with grapevine scale. It is considered to be a predator of eggs of grapevine scale, and possibly frosted scale.

Sampling of parasitoids from a commercial vineyard at Merbein, Victoria, (Table 4, and Figure 2) also showed that *Metaphycus maculipennis*, *Cheiloneurus spp.*, and *Coccophagus* spp. were the common parasitoids of soft scales in vineyards, and were most abundant during spring in both 2006 and 2007, when the scales were mature.

Table 4. Numbers of parasitoids reared from soft scales in relation to scale species predominant on host plant at each site (data summarised from Rakimov 2008, in preparation).

No. sites	Scales present	Host plant	*M.m*	*M.h*	*M.sp*	*Ch.*	*Cocc. spp.*	*C.c*	*E.f*	*O.b*
16	*P. persicae*	grape	312	3	7	25	65			11
3	*P.* near *pruinosum*	grape					6			
2	*C. hesperidum*	grape		11	5	4	15		8	
2	*C.longulus*	grape		6	16			86		
5	*P. persicae*+ *C. hesperidum*	grape	3901	2	4	467	67		31	19
2	*P.persicae*+ *C. longulus*	grape	3	1	1	2				
3	*P. persicae*+ *P.* near *pruinosum*	grape	22			2	126			2
1	*P.* near *pruinosum*	stone fruit				3	21			

* *M.m = Metaphycus maculipennis*, *M.h = Metaphycus helvolus*, *M.sp = Metaphycus sp.* , *Ch. = Cheiloneurus sp.*, *Cocc. = Coccophagus spp., C.c = Coccophagus ceroplastae*, *E.f = Euryischomyia flavithora*, *O.b = Ophelosia bifasciata*.

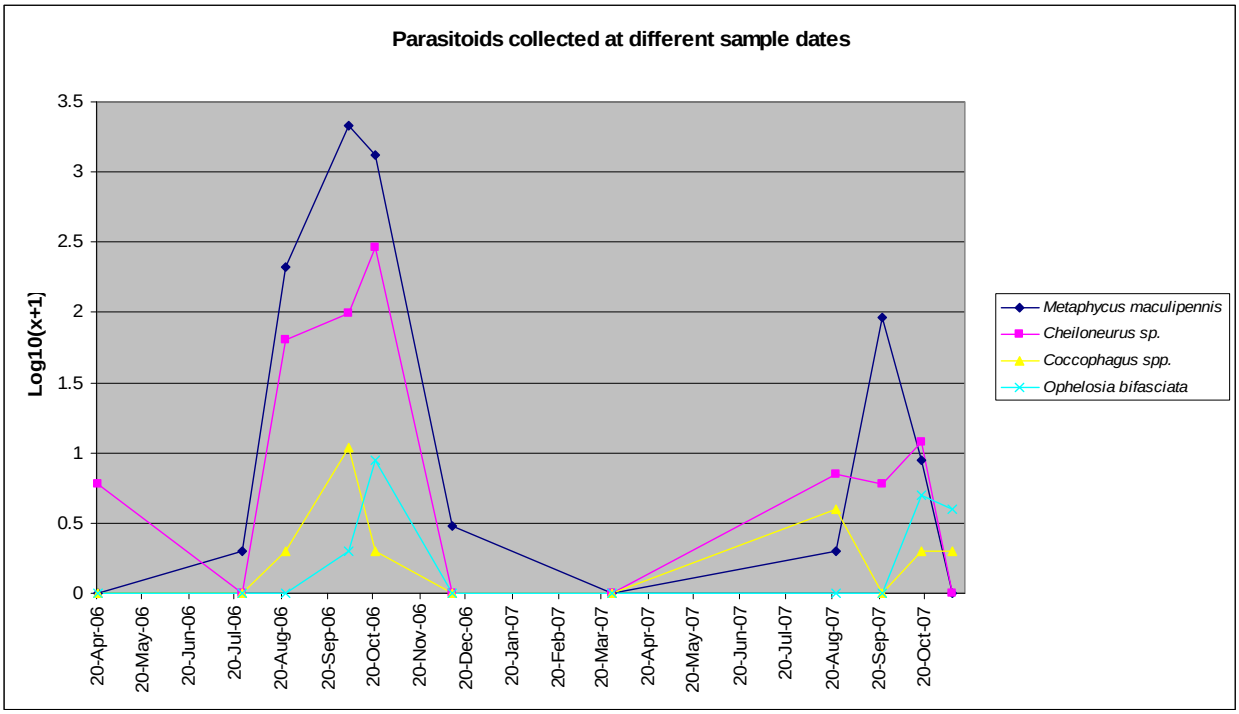


Figure 2. Numbers (expressed as $\log_{10}$ (x+1)) of the predominant scale parasitoids collected from a Chardonnay vineyard at Merbein, Victoria at different sample dates.

Predators

The native ladybird beetle, *Rhyzobius submetallicus* (tentative identification), was collected from vineyards infested with grapevine scale, and to a lesser extent, frosted scale. In vineyards, the larvae, pupae, and cast skins of *Rhyzobius* were often found under these scales. Field collected *Rhyzobius* larvae fed on unhatched eggs of grapevine scale in the laboratory. *Rhyzobius* spp. ladybirds are recorded as feeding on other soft scales, including soft brown scale (Waterhouse and Sands, 2001).

The caterpillar of the native Noctuid moth, *Mataeomera dubia*, is a predator of various scale insects including grapevine scale, soft brown scale, and nigra scale. *M. dubia* was found beneath mature grapevine scale in October, probably feeding on scale eggs or crawlers. In Western Australia, the caterpillar of the native moth *Pyroderces* sp. was found beneath mature grapevine scales.

Cryptolaemus montrouzieri is a native ladybird that is a common predator of mealybugs. In this study, it was collected from samples of grapevine scale and frosted scale in two vineyards at Mildura, Victoria.

Green lacewings are common in vineyards during spring, and field collected larvae fed on eggs of grapevine scale in the laboratory. The lacewings were not identified to species.

Ants

Ants were collected from 21 vineyard locations in mainland Australia (Table 5).

Table 5. Ants collected from grapevines in different States and sites in mainland Australia (data from Rakimov 2008, in preparation).

Ant species	**Number of sites in each State**	**Location of sites (State and region)**
Iridomyrmex spp. (meat ants)	4 3 4 5 3	WA – Swan Valley, Gin Gin, Margaret River SA – Riverland Vic – Sunraysia, Rutherglen NSW – Sunraysia, Hunter Valley, MIA Qld – Stanthorpe
*Ochetellus glaber (*black house ant)	1 2 3 2	WA – Swan Valley SA – Riverland NSW – Sunraysia, Hunter Valley Qld – Stanthorpe
Rhytidoponera metallica (green head ants)	2 1	NSW – Hunter Valley, MIA Qld – Stanthorpe
Paratrechina sp.	2	Vic – Swan Hill NSW - Hunter Valley
Camponotus nigroaeneus group (sugar ants)	1	Qld – Stanthorpe
Crematogaster sp	1	WA – Swan Valley
Doleromyrma darwiniana	1	Qld – Stanthorpe
Linepithema humile (Argentine ant)	1	Margaret River
Monomorium kilianii	1	SA – Riverland
Notoncus sp	1	Qld – Stanthorpe

The most common ants collected (19 locations) were meat ants, *Iridomyrmex* species, some of which were identified to "*suchieri*" group, or to species (*Iridomyrmex purpureus*). The *Iridomyrmex* ants were observed attending grapevine scale and soft brown scale to collect honeydew. Meat ants are aggressive to other ant and insect species, and form large nests on areas of bare ground.

Argentine ant, *Linepithema humile,* while only found at one location, is also an aggressive predator of other insects, a scavenger and honeydew collector.

Several of the other ants collected, particularly black house ant, green head ants, and sugar ants were attracted to honeydew excreted by soft scales.

6.3 Distribution and abundance of soft scales in a commercial vineyard

The relative numbers of scales on the wood and shoots of the grapevines varied during the season, influenced by seasonal changes and cultural practices in the vineyard (Table 6). The sampling unit consisted of a shoot (green during the growing season and lignified shoots less than 1 year old in autumn-winter), together with the internodal section of cane or spur (greater than 1 year old) from which the shoot originated.

At budburst (early September) in 2006 and 2007, the sample unit changed from the previous season's growth (which is then categorised as "wood>1 year"), to the new season growth, consisting of the internode of the cane and the new shoot growing from the bud present on the internode. Thus before budburst, the numbers presented in Table 6 are the scale population is present on wood from the previous season, and immediately after budburst, the numbers represent mature scales on I year old wood and newly emerged crawlers that colonised new shoots, leaves and wood.

Table 6. Mean numbers (n=5) of grapevine scales on wood and shoots of Chardonnay grapevines at Merbein, Victoria. Data summarised from Rakimov, 2008 (in preparation).

Season	**Date sampled**	**Wood> 1 year**			**Shoots**		
		Live	**Dead**	**Parasitised**	**Live**	**Dead**	**Parasitised**
2005/06	16 Mar	0	0	0	68.0	1.2	0
	20 Apr	0	0	0	16.2	0.2	0.4
	16 May	10.6	0	0	29.6	0	0
	23 Jun	8.4	0	0	67.4	3.2	0.2
2006/07	21 Jul	14.6	0.6	0	143.4	5.2	0
	23 Aug	9.4	0.8	0.8	47.0	3.2	5.6
	3 Oct	8.6	0	2.2	0	0	0
	21 Oct	5.2	0.2	0.4	4.4	0	0
	8 Nov	14.6	3.4	0	508.6	21.4	0
	11 Dec	0	1	0	42.4	117.0	0
	15 Jan	0	0	0	51.2	41.2	0
	15 Feb	0	2.4	0	47.2	211.0	0
	27 Mar	0.2	0	0	15.4	1.2	0
	25 Apr	0.6	0	0	21.4	0.2	0
	27 May	4.8	0	0	12.2	0.2	0
2007/08	13 Jul	9	1.2	0	49.2	3.2	0
	22 Aug	7.6	0	0.2	11.6	3.2	0
	20 Sep	1.2	0.4	0	4.8	0	0
	18 Oct	1.4	0	0.2	5.0	0	0
	1 Dec	0.8	0.6	0	19.6	6.8	0

The relative distribution of scales on the sampled shoots changed during autumn – winter (Figs 3, 4), and again during spring (Fig.5). In March and April, there was a low proportion of scales

on the wood, and most scales were on the leaves and stem of the lower 5 nodes of the sampled shoots. In May, June, and July the proportion of scales on the wood increased markedly, presumably as scales moved from the senescing leaves to the stems and wood. Most leaves had dropped by June, and the vines were machine pruned to short (3-6 bud) spurs by August, when all surviving scales were on the wood or stems of the spurs.

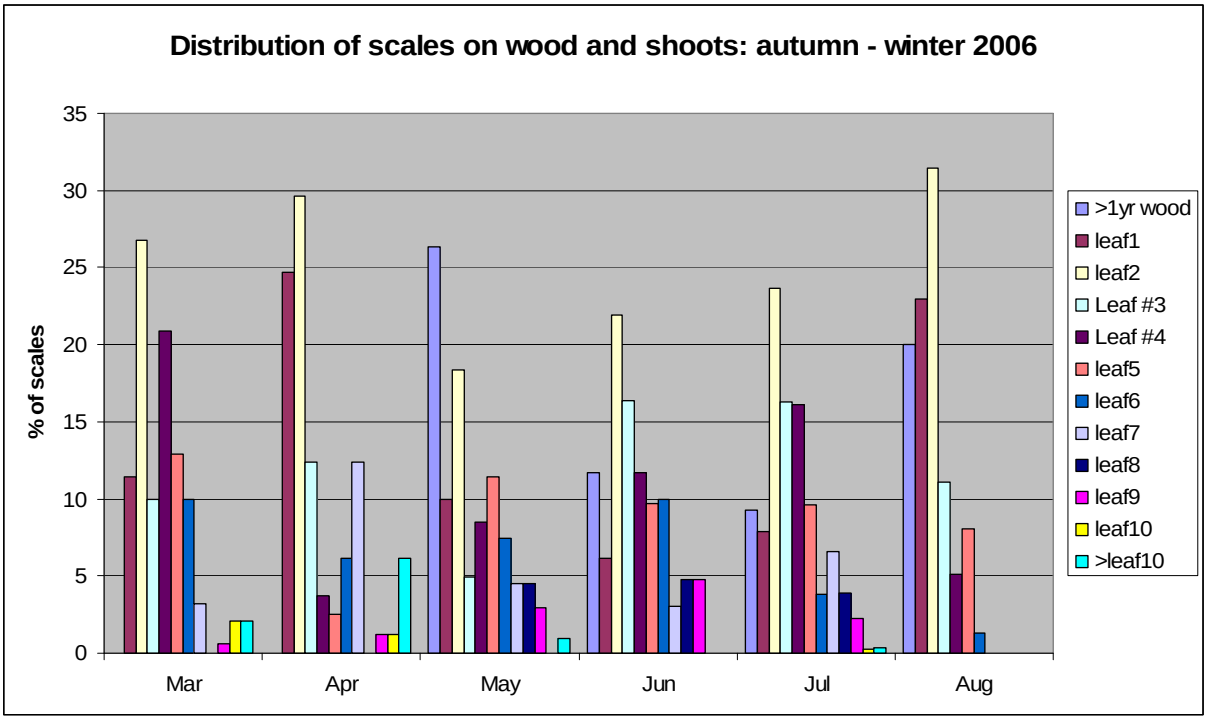


Figure 3. The proportion of scales at different positions along the sampled wood and shoots in samples taken during March to August, 2006.

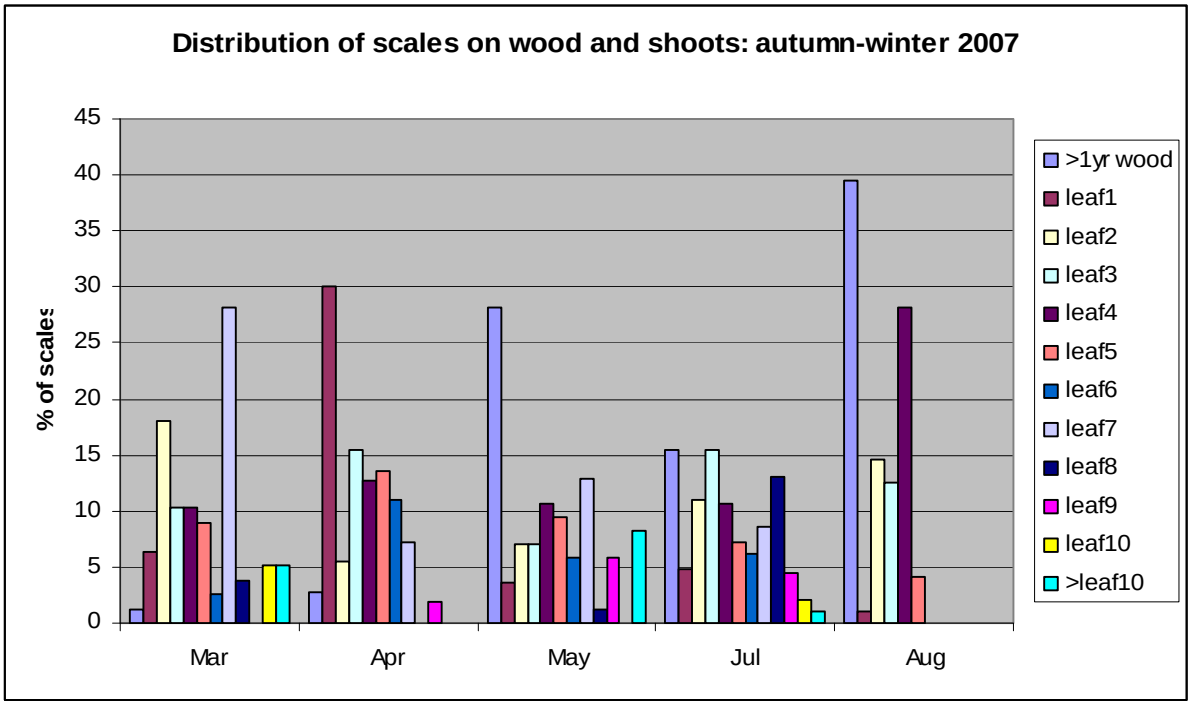


Figure 4. The proportion of scales at different positions along the sampled wood and shoots in samples taken during March to August, 2007**.**

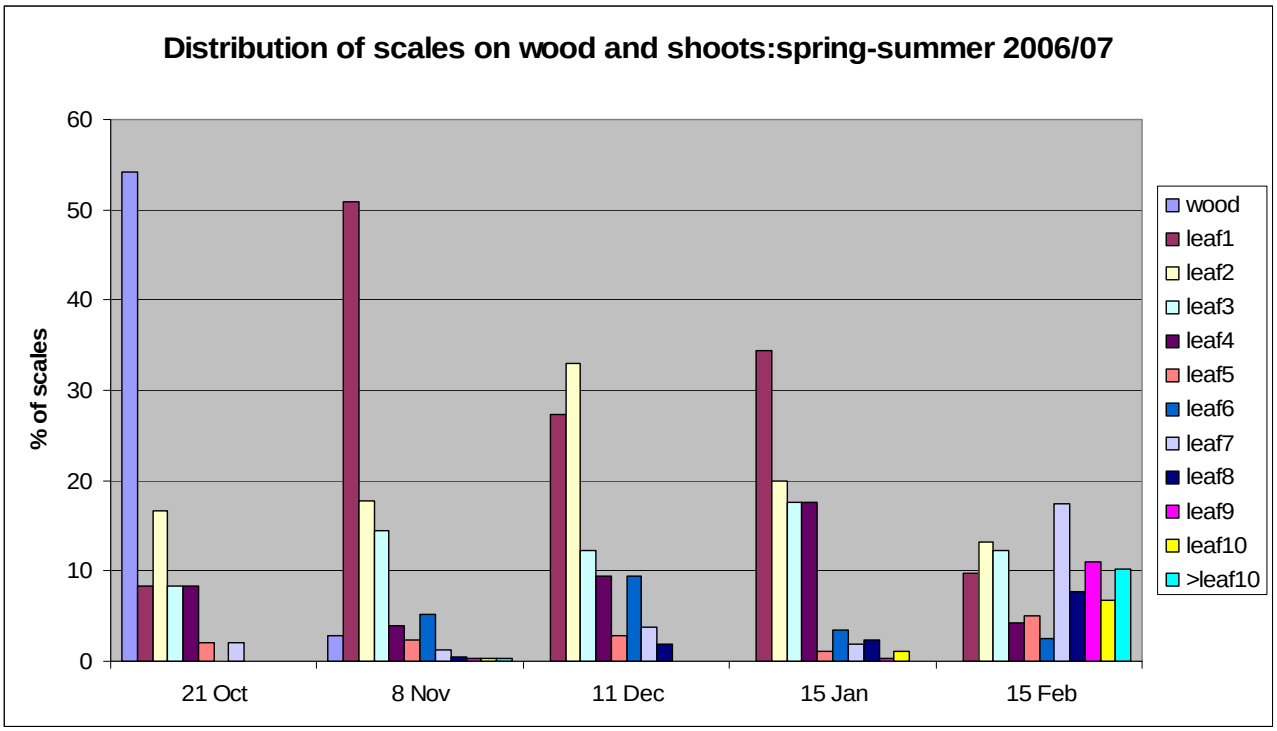


Figure 5. The proportion of live scales at different positions along the sampled wood and shoots in samples taken during October 2006 to February, 2007**.**

The live scales in samples at 3 October, 2006 (about 3 weeks after budburst) were present on previous season's wood only (Table 6). However, during October and November, the scale crawlers had colonised most of the basal nodes on the shoot, and by February the proportion of live scales along the shoot was more evenly distributed (Fig. 5).

In 2006/07, numbers of scales were greater than in the unusually hot and dry 2007/08 season (Table 6). In both seasons, the numbers of live scales on the sampled shoots increased in July, and then declined during August and September. The numbers of dead and parasitised scales does not account for the decline in numbers of live scales. The removal of wood and scales on the wood during mechanical pruning in late winter is the likely reason for decline in numbers of scales in August-September.

The scales matured and produced eggs in August-September each year. In 2006/07, there was a marked peak and then decline in live scales on shoots during November-December. The numbers of dead scales on shoots was high in December, January and February of 2006/07 (Table 6).

Effects of parasitoids, particularly *Metaphycus maculipennis*, on the abundance of grapevine scales on Chardonnay grapevines

The maturing female scales were parasitised in late winter and spring by *Metaphycus maculipennis* and *Cheiloneurus* sp. (fig 2). In early spring 2006, *M. maculipennis* (and *Cheiloneurus* sp.) parasitised about 20% of live grapevine scales, with the adult parasites emerging during the period that crawlers were colonising the new shoots and leaves. No parasitism was recorded during late spring and summer, and it is not known how *M.maculipennis* survives during the summer and autumn.

One possibility is that *M.maculipennis* lays eggs in juvenile scales during spring, and that the parasitoid eggs remain quiescent until the scale grows larger in autumn and winter. Many of the young scales in the spring and summer samples were dead, and up to 6% of the live scales

showed a “black spot” symptom during this period. The numbers of dead scales and scales with the “black spot” symptom show similar trends (Fig. 6). The “black spot” symptom may have been caused by egg laying activities of the parasitoids, or encapsulation of parasitoid eggs, but the cause was not verified.

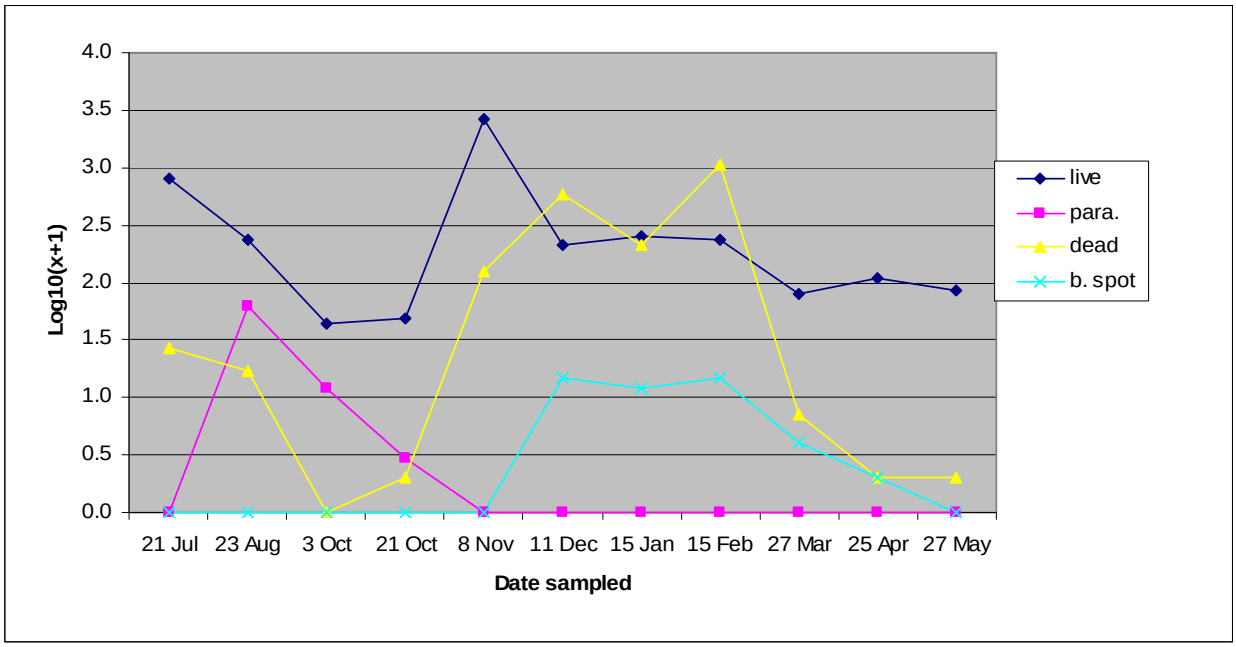


Figure 6. Numbers (as $\log_{10}(x+1)$) of live , parasitised , dead scale, and live scale showing “black spot” symptoms in samples taken from a Chardonnay vineyard at Merbein, Victoria during 2006/07. Data from Rakimov 2008 (in preparation).

Cheiloneurus spp. are hyperparasitoids of *M. maculipennis*. In a sample of 53 individual scales collected from Chardonnay grapevines at Merbein, Victoria on 13 October, 2006, 13 scales were parasitised by *M. maculipennis* alone, and 40 scales by *M. maculipennis* in combination with *Cheiloneurus spp.* and occasionally other species. There were no parasitised scales where *Cheiloneurus spp.* were the only parasitoids present, which indicates that *Cheilonurus spp.* occur only as hyperparasitoids of *M. maculipennis.*

In scales parasitised by *M. maculipennis* alone, the mean number of *M. maculipennis* emerging from the scales was 27.3 (n=13, range 3-62, SE_M = 5.0), whereas in scales parasitised by *M. maculipennis* in combination with *Cheiloneurus spp.* and other species, the mean number of *M. maculipennis* emerging from the scales was 22.5 (n=40, range 1-51, SE_M = 2.0). This data indicates that the presence of hyperparasitoids, in particular *Cheiloneurus spp.*, has a marginal effect in reducing the number of progeny of *M. maculipennis* produced from a grapevine scale.

The effect of parasitism by *M. maculipennis* (and *Cheiloneurus spp.*) on mature grapevine scale was to kill the scale, but this did not necessarily prevent the scales from producing eggs and crawlers. In a subsample of 20 individual scales from the above sample collected on 13 October, 2006, the mean number of eggs and crawlers produced by unparasitised scale was 2419 (n=14, range 110-4343, SE_M =336). In contrast, the mean number of eggs and crawlers produced by parasitised scale was 337 (n=6, range 2-1652, SE_M =265).

The effects of parasitism of the mature scales in relation to reproductive capacity of the scales were to be further investigated in 2007. However, no parasitism was recorded in a sample of 30 scales, consistent with the low rates of parasitism recorded from the study vineyard at Merbein (Table 6). Further research is desirable to better quantify the effects of parasitism by *Metaphycus maculipennis* on reproductive potential of grapevine scale.

7. Outcomes and conclusions

The presence of soft scales in vineyards is not obvious to many grapegrowers, because of their small size and cryptic habits. The dead mature scales from the previous season and overwintering juvenile scales are most obvious after leaf fall in winter. However, scale numbers are often underestimated because juvenile scales overwinter on the underside of canes or spurs, and underneath bark on the trunk or cordon of the vines. The identification of different species is difficult during winter as the immature stages of grapevine scale, frosted scale, soft brown, and nigra scale are superficially similar to the observer.

This study has shown that soft scales are common and abundant pests in many Australian vineyards. While grapevine scale is the most common and widespread soft scale in vineyards, the presence of mixed infestations with frosted scale and to a lesser extent soft brown scale in many vineyards was unexpected. Long soft scale, nigra scale, and black scale were not common in vineyards, but could become locally important. For example, the expansion of table grapes into warmer areas may increase the importance of long soft scale as a vineyard pest.

The information on the distribution of grapevine scales in different regions, within vineyards, and within vines, will help grapegrowers to assess the extent of their scale problems, and to improve their management of the scales. Surveys of vineyards for grapevine scales need to be extensive, as the scales may be randomly distributed across most of the vineyard. While surveys are usually more effective and easier in winter, the presence of ants on grapevines is a good indicator of the presence of soft scales or other honeydew producing insects during the growing season.

In the short term, the descriptions and photographs of soft scales presented in this report (Appendix 9.1) will help grapegrowers to recognise and manage scale populations in their vineyards. The presence of mixed infestations of soft scales, and the different levels of biological control of the different species adds considerably to the complexity of pest management.

The uncertainty about the taxonomy of frosted scale in Australia has highlighted the need for further taxonomic and genetic studies of the soft scales on grapevines in Australia. The molecular diagnostic techniques explored in this study have potential applications as quick and reliable diagnostic tools for both adult and more particularly juvenile stages of the scales. The amplification of hymenopterous DNA from the scales shows the further potential to determine which parasitoids are parasitising which scales, and when. These are areas for further research that will have practical application for grapegrowers and pest management specialists.

The native ladybird, lacewing, and moth predators of grapevine scales are likely to be effective in reducing high scale populations in winter and spring. One marked feature of the populations of grapevine scale was the big reduction in numbers of juvenile scales on leaves during summer. The cause(s) of this reduction was not determined, but it may be associated with parasitism or host feeding by parasitoids, particularly *Metaphycus maculipennis*. Further research on the biology of *Metaphycus maculipennis* and its effects on scale populations is required.

In this study, *Metaphycus maculipennis* was the most abundant and effective parasitoid of grapevine scale, *Parthenolecanium persicae*. Although the maximum rate of parasitism was only about 20% in October 2006, previous observations have indicated parasitism rates of over 60% of mature female grapevine scales in some years. Grapevine scale seems to be the only host of *Metaphycus maculipennis* in Australia. The causes of the apparent differences between seasons in rates of parasitism, confirmation of the parasitoid effects on reproductive potential of grapevine scale, and the parasitoid life cycle during summer and autumn are issues that remain to be resolved.

Control of grapevine scale, and other soft scales, in vineyards is warranted when high numbers of scales are present. Control measures should take into account the effectiveness of natural enemies, and the role of ants in attending scales and protecting them from natural enemies. Reduction of ant populations in vineyards, the use of pesticides that have little residual toxicity to natural enemies, and spray applications that target the lower surfaces of wood and leaves are basic requirements for effective pest management.

While the biology of grapevine scale and frosted scale are very similar, the level of biological control of the two species is very different. *Metaphycus maculipennis* was a common and seemingly effective solitary parasitoid of juvenile grapevine scale, and a gregarious parasitoid of mature grapevine scale. However, no gregarious parasitoids were reared from mature frosted scale. The absence of effective parasitoids of frosted scale, *Parthenolecanium* near *pruinosum*, represents a long term opportunity to introduce biological control agents to Australia for better control of this pest. *Metaphycus californicus* is recorded as an effective solitary and gregarious parasitoid of frosted scale (*Parthenolecanium pruinosum*) in California, and may be a potential candidate for import, if and when the taxonomy of "frosted scale" in Australia is resolved. As frosted scale affects both grapes and stone fruit, there would be potential benefits across the horticultural industries from improved biological control of frosted scale.

8. Recommendations

Effective management of grape pests relies on accurate identification of the pest, and then choice and use of sustainable methods to control the pest. This study has shown that management of soft scales in vineyards is complicated by the presence of grapevine scale, frosted scale, soft brown scale, nigra scale, long soft scale, and Saissetia sp. (probably black scale, *Saissetia oleae*). These scales occurred separately or in different combinations (Table 1). The extension publication produced as part of this project should be used as part of a series of practical workshops for grapegrowers, preferably carried out in late winter in regional areas, and led by viticultural extension specialists. The objectives of the workshops would be to provide grapegrowers with the information required to identify their soft scale pests, and to decide on the best options for sustainable control.

The status of "frosted scale" in Australia needs to be resolved. This will require further taxonomic and molecular research, in collaboration with expert taxonomists, to clarify whether "*Parthenolecanium* near *pruinosum*" is a distinct species of scale. This in turn will have implications for any future research on the potential to introduce parasitoids to Australia for biological control of frosted scale.

Once the taxonomy of frosted scale is determined, industry funders (GWRDC and HAL) should consider a feasibility study into increasing the biological control of soft scales on grapevines and fruit trees in Australia. The applied research on biological control of citrus scale pests by the late Dan Smith of QDPI, in conjunction with suppliers of biological control agents and IPM services, is an inspirational model for future work.

The future use of molecular technologies to identify soft scales, and their parasitoids, is an opportunity to provide new practical tools that will benefit both grapegrowers and researchers. Questions about which species of parasitoid or predator is affecting which pest species, when, and to what extent are basic questions that are often extremely difficult to answer with conventional entomological techniques. Further research into the practical application of molecular technologies in insect ecology should be an area of strategic investment by research agencies seeking to provide the knowledge required to achieve sustainable integrated pest management.

9. Appendices

9.1 Communications

9.1.1 Extension publications and presentations

Bernard, M., Horne, P.A., Papacek, D., Jacometti, M.A., Wratten, S.D., Evans, K.J., Herbet, K.S., Powell, K.S., Rakimov, A., Weppler, R., Kourmouzis, T., and Yen, A.L. (2007). Guidelines for environmentally sustainable winegrape production in Australia: IPM adoption self-assessment guide for growers. Australian Grapegrower and Winemaker, March 2007, 24-35.

Rakimov, A. (May 2007). Soft scale insects in Australian Vineyards (talk). Department of Primary Industries Plant Health Forum. Grains Innovation Park, Horsham, Vic.

Rakimov, A. (September 2007). Soft scale insects in Australian Vineyards (talk). Australian Entomological Society Conference. Beechworth.Vic.

Rakimov, A. (2005) Wanted dead or alive: grapevine scales. Murray Valley Winegrowers' Grapevine May/June, 11.

Rakimov, A. (2007) Soft scale insects in the Australian vineyard (talk). In 'Riverlink Wine Grape Symposium, 14 June 2007, Mildura, Victoria.'

Rakimov, A. (2006) Have you got scale? Wine Industry Newsletter (W.A Dept of Agriculture) 81, 12.

9.1.2 Draft Fact Sheet: Soft scales (Coccidae) on grapevines in Australia

Authors: A Rakimov and G. A. Buchanan

Introduction

Grapevine scale, *Parthenolecanium persicae*, is a well known and widely distributed pest of grapevines in Australia. A recent study of soft scales on grapevines in Australia (Rakimov 2008, in preparation) has shown that five other soft scales are present on grapevines. The most common of these are frosted scale, *Parthenolecanium* near *pruinosum*, and soft brown scale, *Coccus hesperidum,* which were often in mixed infestations with grapevine scale. The taxonomy of frosted scale needs to be resolved, as specimens from Australia were not identical to type specimens of *Parthenolecanium pruinosum* (Ben-Dov, personal communication). For the purpose of this document, the common name of "frosted scale" has been used for *Parthenolecanium* near *pruinosum.*

Nigra scale, *Parasaissetia nigra*, and a *Saissetia* sp. (probably black scale, *Saissetia oleae*) were found in a few vineyards and backyard grapevines, but are not considered as significant grape pests. Long soft scale, *Coccus longulus,* was found on table grapes at Carnarvon and winegrapes at Margaret River, WA, and in the Hunter Valley of NSW. It may become a minor grape pest as table grapes become more common in warmer areas of Australia.

Identification of scales

It is difficult to distinguish the different species of soft scales on grapevines, particularly the juvenile stages. However, mature females on grapevines in spring have characteristic features which help to visually distinguish the different species (Table 1).

Table 1. Characters that can help to visually distinguish mature soft scales found on grapevines in Australia.

Scale species	Mature females	Eggs and/or crawlers
Grapevine scale	Oval shape, about 7mm long, dark brown scale.	Yellow eggs laid in mass beneath the body of the adult scale, crawlers yellow.
Frosted scale	Oval shape, 6-8mm long, strongly convex. Scale dark brown, sculptured and covered with white powdery wax	White eggs, laid in mass beneath the scale body. Crawlers white.
Soft brown scale	Oval shape, 3-4 mm long, yellow-brown mottled with brown spots.	Crawlers are light brown, born alive.
Black scale	Oval shape, 3-5 mm long, convex, scale black to dark brown. Ridges on top surface of scale forming a "H" shape, most obvious in early stage adults.	Pink eggs, laid in mass beneath the scale body. Crawlers light brown.
Nigra scale	Elongate oval in shape, 3-4 mm long. Smooth, shiny dark brown to black scale.	Eggs laid in mass beneath the scale, crawlers light brown.
Long soft scale	Elongate oval shape, 4-6 mm long, yellow to grayish brown, with visible eye spots.	Crawlers born alive.

Life cycle of grapevine scale and frosted scale.

The life cycle of grapevine scale and frosted scale is very similar. Both scales have predominantly female populations, although Rakimov (2008) has recorded the presence of male grapevine scale in Australian vineyards. There is generally only one generation of grapevine scale and frosted scale per year.

In autumn and early winter, juvenile grapevine scales and frosted scales move from leaves to the shoots and wood of the grapevines. The juvenile scales are most obvious on the underside of canes and spurs, but are also found under the bark of the grapevines (Fig 1).



Figure 1. Immature grapevine scales on a dormant cane during winter (photograph by A. Rakimov).

In late winter and spring, they grow to mature females and produce up to 5000 eggs. At this stage, grapevine scales can be distinguished by the shape and colour of the adult female (Fig. 2), and the colour of the eggs (Table 1). The adult females die after laying eggs, which remain under the scale cover of the dead female until the crawlers hatch. They colonise the leaves and shoots of grapevines after budburst, settling on the newly emerged leaves and shoots.

The young scales are mostly on the underside of the basal leaves of the shoots, but are small, translucent and difficult to see without a microscope or magnifying hand lens. One obvious clue to the presence of soft scales on grapevines the activity of ants, which attend the juvenile and maturing scale to harvest honeydew excreted by the scales.

The scales remain on the leaves and green shoots, growing slowly during the summer months, until moving from the leaves and shoots in autumn.

Effects of scale on grapevines

In high numbers, grapevine scales can reduce the vigour of grapevines, but more commonly the main consequence is the production of honeydew by soft scales, which attracts ants and is a substrate for the development of sooty moulds. The honeydew and sooty moulds reduce the quality of grapes for fresh markets, and where the grapes are processed for dried fruit or wine. The ant activity on the grapevine disrupts biological control, not only of the grapevine scale, but also of other honeydew producing pest insects such as mealybugs, which can lead to increased and sustained pest populations. Ant suppression (e.g. by vineyard soil management or treatment of ant nests) should help sustain biological control and thus reduce populations of honeydew producing insects.



2.1 Grapevine scale, mature females.



2.2 Frosted scale, mature female.



2.3 Soft brown scale, adult female and juveniles.



2.4 Long soft scale, females and crawlers.

Figure 2. Four species of soft scales found on grapevines in Australia (Photographs by A. Rakimov).

Biological control of soft scales on grapevines

The grub of native ladybird beetle, *Rhyzobius submetallicus*, and the caterpillar of the native moth *Mateomera dubia*, and the larvae of green lacewings are useful predators of the eggs and crawlers of grapevine scale. They are probably most effective in reducing high populations of soft scales on grapevines.

There are several minute wasps that parasitise the different soft scales. The most common and effective parasitic wasp attacking grapevine scale was *Metaphycus maculipennis*, a solitary parasite of juvenile scale and a gregarious parasite of the mature grapevine scales. Up to 62 wasps of *M. maculipennis* were recorded emerging from a single grapevine scale (Rakimov 2008). Parasitism of the mature scales by *M. maculipennis* reduces the number of eggs produced by the female scale. The parasitised scales are easily recognised by the multiple emergence holes in the scales (Fig 3).

Common parasitic wasps reared from soft scales on grapevines are *Metaphycus helvolus, Coccophagus lycmnia,and C. semicircularis. Metaphycus helvolus* is a parasite of soft brown scale, nigra scale, and black scale, while *C. lycmnia* and *C. semicircularis* parasitise soft brown

scale and black scale (Malipatil et al 2000). *Coccophagus ceroplastae* was recorded as a parasite of long soft scale.



Figure 3. Exit holes of parasites in grapevine scale. Note the males of *Metaphycus maculipennis* in the foreground (photograph by A. Rakimov).

Management of scale infestations in vineyards

The best time for growers to assess scale populations in their vineyards is during winter, after leaf fall. The immature scales can be seen with the naked eye or a hand lens, and are most abundant on the underside of canes or spurs. Where scales are found on a vine, a good idea of the extent of the infestation can be found by stripping loose bark away to expose scales sheltered beneath the bark. Both grapevine scale (Fig. 2) and frosted scale will appear as dark, oval shaped scales, but it is difficult to distinguish between the juvenile stages of these species.

The scale infestations across the vineyard are typically patchy, with some vines having high scale populations, and others lightly infested. Marking of the infested vines (e.g. with flagging tape) is useful where later spot treatment of the heavily infested vines is planned.

Spraying infested grapevines with oil is an effective way of controlling the scales. As pruning operations remove some of the scale infested wood, it is more economical and efficient to spray after pruning, but care must be taken to complete spraying while the vines are fully dormant, as winter oil sprays can have phytotoxic effects if spayed too close to budburst. The spray machines should be set up to achieve good coverage of the underside of canes or spurs. Spot spraying of the vines with dense infestations only will help preserve predators and parasites of the scales on the unsprayed parts of the vineyard.

Growers should also inspect scale infestations in early spring, to determine the species of scale present (Table 1, Figure 2), and in the case of grapevine scale, the extent of parasitism of mature scales as evidenced by the exit holes in the parasitised scales (Figure 3). This information is useful for planning integrated pest management practices in the vineyard.

During the growing season, scales are on the stems and underside of leaves. The scale populations on leaves are likely to be reduced by predators such as green lacewings and by high temperatures, and in some cases by broad spectrum pesticides applied for control of other vineyard pests. The presence of ants attending the scales is a useful indicator of scales and other honeydew producing insects. The suppression of ant populations may assist in reducing populations of honeydew producing insects. In most cases it is doubtful that specific control

measures are warranted for scales during the growing season on the basis of economic damage, and the effectiveness of sprays will depend on the ability to achieve spray coverage on the underside of leaves. Insecticidal options for scale control in vineyards are discussed in Bernard et al 2007.

References

Bernard et. al. (2007). Guidelines for environmentally sustainable winegrape production in Australia: IPM adoption self-assessment guide for growers. Australian Grapegrower and Winemaker, March 2007.

Malipatil, M.B., K.L. Dunn, and D. Smith (2000). An illustrated guide to the parasitic wasps associated with citrus scale insects and mealybugs in Australia. Department of Natural Resources and Environment, Institute for Horticultural Development, Private Mail Bag 15, South Eastern Mail Centre, Victoria 3176.

Rakimov A. (2008, in preparation). “Soft scales on grapevines in Australia: aspects of their distribution, ecology and biological control”. PhD Thesis, University of Melbourne.

9.2 Intellectual Property

The information arising from this project is publicly available.

9.3 References

Anon. (1987). Integrated pest management for walnuts. University of California, Statewide IPM Project, Publication 3270, p. 54-55.

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Waterhouse, D.F., and D.P.A. Sands (2001). Classical biological control of Arthropods in Australia, CSIRO Entomology, Canberra.

Wilson, F. (1960). A review of biological control of insects and weeds in Australia and New Guinea. Commonwealth Agricultural Bureau, Technical Communication No.1. Commonwealth Institute of Biological Control, Ottawa, Canada.

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9.5 Data and collections

The various insects identified in this project are held in the Victorian Agricultural Insect Collection, and the Australian National Insect Collection. Additional specimens are in the collections of the taxonomic specialists who assisted in their identification.

For detailed data, see Rakimov A. (2008, in preparation). “Soft scales on grapevines in Australia: aspects of their distribution, ecology and biological control”. PhD Thesis, University of Melbourne.